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The Spawning of the Grunion (Leuresthes tenuis)

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July 15, 1919

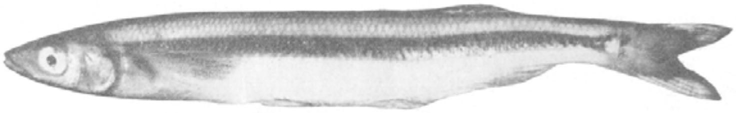

Fig. 1. The Grunion, *Leuresthes tenuis*. Male, length 5¾ inches, taken April 16, 1919, at Long Beach, California.

Fig. 1. The Grunion, Leuresthes tenuis. Male, length 5 ¾ inches, taken April 16, 1919, at Long Beach, California

2. The Spawning of The Grunion (Leuresthes tenuis.)[*]

By Will F. Thompson,
assisted by Julia Bell Thompson

On moonlit nights during the high tides of March, April, May and June, a small smelt comes in on the long sandy beaches of California. It comes in with the sweep of the water up the beach as the waves break, and lies for a moment glittering in the faint light, then squirms and flops back into the wash of the next wave. Along the whole magnificent sweep of broad sandy shore at Long Beach, crowds of people gather to pick up these fish, by the light of the moon, and of bonfires, and of flashlights. Some content themselves with picking up the stranded fish; others utilize wire screens, or even portions of beach seines, catching the smelt as they venture inshore. The fish they obtain are less than the length of one's hand, slender, with a broad lateral stripe, and very plainly of the smelt family. At Long Beach no name other than "grunion" is ever heard, although one gleans from scientific works such names as "silversides" and "little-smelt." Those who gather this "grunion" know that it comes in to spawn its eggs, but of the marvelous story that lies ready to discovery, they know not a whit. The crowds of bathers who follow in their footsteps on succeeding days, little think that four inches below their feet is unfolding one of the really remarkable stories in the annals of natural history.

Surely the grunion has a purpose in thus venturing out of its native element, to lay its eggs in the sand. In some way the act must serve the species, must aid it in its survival. It must escape its enemies, or obtain favorable conditions for development. Other smelts lay their eggs very differently, attached to the rocks or the bottom of the ocean by slender stalks or filaments. Many species migrate into brackish or even fresh water to spawn, while other genera or species are entirely confined to fresh water. Even in species apparently closely related, the spawning habits have become diverse, perhaps under the pressure of the struggle for survival. Fish, smelts and others, lay their eggs in every conceivable marine locality where suitable conditions may be obtained, but it remains for the "grunion" to utilize what is practically dry land.

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[*] California State Fisheries Laboratory. Contribution No. 8.

For that is actually what it is doing when it ventures inshore as far as the high tides will carry it. The eggs are laid in the sand as far down as the fish is able to bury them, and far above the level of the average tide. The way in which it does this, the history of the eggs in the sand, and the story of their escape are interest-compelling.

3. The Spawning Run

The grunion comes the second, third, and fourth nights after the full of the moon, according to popular tradition; therefore but once a month and shortly after the highest tides which accompany the full moon. The tides are then highest at about nine o'clock (ten o'clock according to summer time). Shortly before the tide is farthest in, the grunion may be taken with a beach seine placed athwart the wash of the waves. At the same time, occasional fish may be picked up on the beach as they are left exposed at the highest point reached by the waves. Very shortly after the time of the highest tide, and when the moon is well up above the horizon the real run commences, and for an hour or more fish may be found in numbers, especially where there is a light run-off or curve in the beach which produces a swirl in the wash of the waves. Occasionally thousands of fish are within sight at one time. The run diminishes gradually, and finally stops. Our first observations on this run were in April of 1919, on the fifteenth when the moon was full. The first fish were taken on the sixteenth and the last on the night of the eighteenth, thus confirming in a measure the popular belief of the crowds who gather expectantly at the proper time, as given by Mr. J. B. Joplin of Santa Ana, who says, "Three months during the year, usually March, April, and May, on the second, third, and fourth nights after the full moon, at full tide, great schools of them come out in the breakers * * *."[*]

The schools of fish which come in seem to work back and forth on the edge of the beach, and they may be taken some time before they commence to run up the beach. By the use of a short piece of seine, with cork line at the top and lead line below, numbers of fish were taken before high tide time. When the waves washed up the beach the net was lifted, but when the water returned in a torrent the net was dropped and held firmly against the bottom so as to make a manner of bag into which the smelt were carried. Two men captured by this method a bucketful of fish in an hour's work. It seemed possible to do as well by picking up the fish on the beach, but so many people were doing this as to render it very difficult.

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[*] However, we also observed a spawning run in June, the fourth during the season.

The males were nearly twice as abundant as the females in this catch by the seine, as will be evident from the following table:

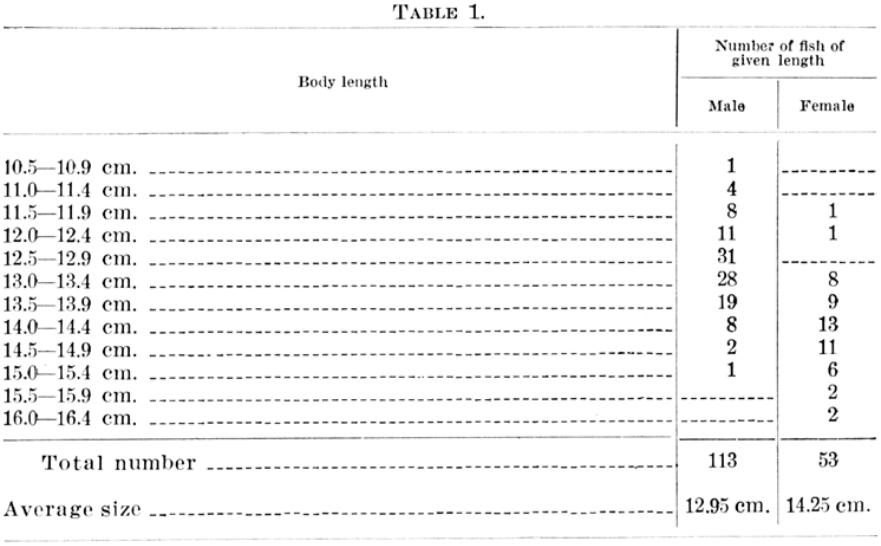

TABLE 1.

Body length	Number of fish of given length	
	Male	Female
10.5—10.9 cm.	1	----------
11.0—11.4 cm.	4	----------
11.5—11.9 cm.	8	1
12.0—12.4 cm.	11	1
12.5—12.9 cm.	31	----------
13.0—13.4 cm.	28	8
13.5—13.9 cm.	19	9
14.0—14.4 cm.	8	13
14.5—14.9 cm.	2	11
15.0—15.4 cm.	1	6
15.5—15.9 cm.	----------	2
16.0—16.4 cm.	----------	2
Total number	113	53
Average size	12.95 cm.	14.25 cm.

TABLE 1

The males were also much the smaller fish, averaging 12.95 centimeters in length without the tail fin, whereas the females averaged 14.25 centimeters. This means 15 centimeters or 5.9 inches total length for the males and 16.6 centimeters or 6.5 inches for the females, a difference somewhat more than half an inch in favor of the females. This difference is, however, much more apparent when the bulk of the fish is considered, for although the length of the average male is roughly 90 per cent of the length of the female, its weight is but 70 per cent, because the weight increases approximately according to the cube of the length. This difference in size allows one to decide readily on the sex of the fish in most cases, and this may be quickly confirmed by squeezing out some of the milt or roe.

The difference between sexes being known, further observations were made on the actions of the fish which had ventured high on the beach.

4. The Spawning

A station was taken near one of those slightly uneven portions of the beach where the water swirled and gathered as it ran off, and in which the fish gathered most abundantly, and careful watch was kept for incoming fish. As soon as a high wave (one in every seven, the passers-by informed us) had passed well up the beach and then receded, fish were to be found lying a few feet below the highest point reached. At first single fish, or perhaps a number of fish, were taken lying on the sand and an occasional one was captured buried tail downwards to the level of the pectoral fins. The latter proved to be females, invariably, and by acting quickly, it was possible to take one, or perhaps more, males in the vicinity of each buried female. If the male, lying flat on the sand, could be seen and captured before it moved, it was very often, indeed almost always, found with its vent lying very close to the buried female. The conclusion is irresistible that actual pairing takes place.

But a further conclusion follows, for surely this elaborate habit must be for a purpose. The females, in thus burying themselves, must be doing so in order to deposit the eggs. The males closely attend the females, and when the latter deposit their eggs the milt is extruded in the sand as the female agitates it. Close, quick observation showed the whole process of pairing and egg laying. In a typical case, two fish were observed lying side by side, heads up the beach, in a small gully near the upper part of the area covered by the waves. The fish, moving very slightly, seemed quiescent for a moment; then the female, stirring the sand with her tail and fins until it became fluid, buried the posterior part of her body, ultimately assuming a vertical position, while the male lay arched around her and in contact with her side. The female twisted slightly to and fro, her body revolving considerably on its long axis, until she had sunk to the level of the pectoral fins. About this time the male flapped away, and was promptly captured for examination. The female then began to bend from side to side slowly and as though fatigued until she emerged from the sand, obviously spent, her abdomen flaccid. The whole process took an average time of twenty to thirty seconds in five cases timed. By digging up the sand the eggs were quickly obtained, buried at a depth of two and a half to three inches at most. In two cases observed, the female actually buried herself an inch and a half or two inches completely under the sand. These completely buried ones were, however, but two among the thirty-five or forty that were watched sufficiently; hence, but a small percentage.

The affair is, however, not a real pairing, for frequently there are four or five males surrounding one female, and in one case two females were seen to mate with one male which lay between them. In fact the mating is accomplished in a casual way, the fish happening to come to rest in the same slight hollow, or in a small group as the swirl of the water left them. Nor do males and females always find each other, for females turgid with eggs may be picked up in numbers after the waves, energetically pursuing their course back into the water. There are certainly, however, the best of reasons to consider the pairing, or mating, as necessary before spawning can occur, for in observing six runs of fish not a single female was caught in the act of burying herself which did not have, or had not had, a male near her.

That this burial was the sole method of laying the eggs could hardly be questioned. A close examination of the sand with the aid of a bright flashlight showed no such number of eggs on the surface as would be expected to be laid by a female, and there were certainly pods of eggs deposited in the sand at varying depths.

5. The Position of the Eggs

To corroborate these observations search was made for the pods of eggs during the next day. It was judged that they should be sought at about-the depth at which the eggs would be buried by a fish of the given size, at most the distance between the vent and the pectoral fins. Measurements indicated that this was approximately two inches. It proved possible, indeed, to find the eggs, but very strangely they were not two inches down. The eggs were found in small masses, or "pods" as they may be termed, unmixed with the sand save at the surface of the pods, and no more moist than their surroundings. But these pods were in various cases the following distances below the surface: 3½ inches; 4; 4½; 4¼; 4¼; 2¾; 3; 2¾; 4¼; 3¾; 2; 6; 6; 5½. These average 4 inches down. Careful comparison of the eggs squeezed from females and the eggs in these pods proved them identical. There was no doubt whatsoever regarding the fact that the pods were those laid by Leuresthes, yet the attainment of a depth of 4½ inches would certainly have buried the fish with the tip of its snout two or three inches under the surface of the sand, something which was observed only occasionally. But where was the error in observation? Certainly if the female had not buried herself that deeply, but had forced the eggs down by the action of her anal and caudal fins, they would have been mixed with sand. This circumstance demanded explanation, which was fortunately obtained and is given later.

Pending this, careful examination was made of the pods and their position. A female 17.1 centimeters in total length, captured in the seine before it had spawned, was opened, and the eggs counted, giving 2,528 eggs. Six pods were carefully dug up on the twenty-third, six or seven days after they were laid, and the counts of eggs were as follows: 1,911; 1,514; 1,479; 2,540; 2,705, with an average of 2,200. It is evident enough that all the eggs in a female of large size were laid in some of the pods, but in the others of lesser number it is possible that only part of the eggs were laid, or that small females laid them. In a female 11.8 centimeters in body length (13.7 centimeters total length) but 475 were counted. Pods containing as few eggs as this were certainly to be found, but in each case were open to the suspicion that parts of them were lost. However, these numbers confirmed the evidence derived from the examination of the structure of the eggs that the pods were laid by Leuresthes.

These pods were, moreover, located in those precise regions in which the adults had been observed to spawn. As has been mentioned, the spawning takes place just below the line (two or three paces) reached by the very highest of the waves, and at about the average height reached by good-sized waves at the height of the tide. At that point the sand is lifted and lightened by the water of the high waves until it is very easy to penetrate, just as any soil will become softened by moisture—in this case excessive. On the most even of beaches there are of course inequalities, and in the gullies the water will collect during the run-offs and remain a trifle longer in a swirl, thus allowing the fish a better chance to burrow before the sand settles. In these localities the pods were most abundant. In the accompanying plate (Figure 2) the area dug over during three days of collecting samples is shown, the level reached by the average good sized wave of a 5.4-foot tide being indicated by a double line. The area in the left-hand side of the chart covered a slight depression and in it more pods were found than on a more even beach. No pods were to be found above or below those shown on the chart, although diligent search was made. Although these pods were laid in sand which was moistened by the larger waves of the high tide, yet they were practically in an environment far from marine in character. The conditions under which the eggs existed were beyond doubt unendurable for eggs such as are taken in the plankton, floating freely in the surface waters of the ocean. Temperature, salinity, and enemies would naturally be expected to vary widely from marine conditions.

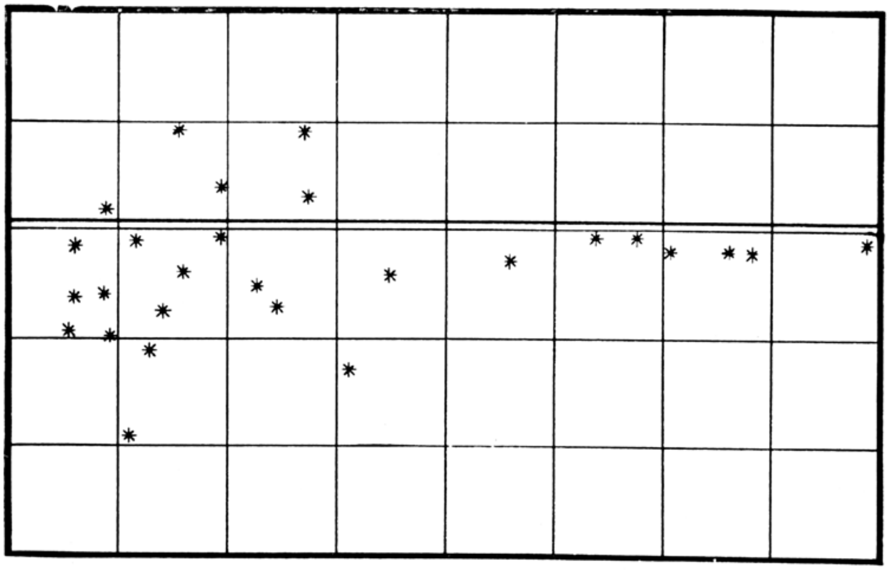

Fig. 2. Locations of pods of *Leuresthes tenuis*, collected April 21, 22, and 23, 1919, at Long Beach. Average highest points of waves during high tides (5.3 feet) of April 16, 17 and 18 indicated by the double line. Squares three feet on each side.

Fig. 2. Locations of pods of Leuresthes tenuis, collected April 21, 22, and 23, 1919, at Long Beach. Average highest points of waves during high tides (5.3 feet) of April 16, 17 and 18 indicated by the double line. Squares three feet on each side

6. The Enemies of the Eggs

In searching for pods, note was made of possible enemies, and it was found that numerous species of animals inhabited the sand. Certain of these were marine, others terrestial, the beach at high tide line representing an area apparently invaded by hardy members of each group. Annelids (fish worms) and amphipods (sand-fleas) were abundant, but in no case were they connected with the destruction of fish eggs. An isopod,[1] however, was found in the very center of a pod of eggs. Whether it was feeding on the eggs or simply happened to stray in is unknown.

The case is different with a beetle, Saprinus sulcifrons Lec., a member of the family Histeridæ. This species was found very frequently in the immediate vicinity of the pods, and very often in the midst of the eggs. Occasionally warning of the presence of eggs near by was given by the discovery of the beetle. Its powerful legs render it a most efficient borer in the sand and it apparently ranged widely in search of food. When placed in a vial of sand with a numbered lot of eggs it soon consumed them, thus proving without doubt the cause of its presence in the pods. It was not to be found during the days immediately following the depositing of the eggs, but appeared later, in so far as the limited observations indicated. Blatchley,[2] a specialist on beetles, says of this group, "Members of this genus live mostly in carcasses, especially those of dead fish along shores and lakes." Also, "These beetles were formerly thought to be scavengers, but it is now believed they are predaceous in all stages, devouring larvæ of diptera which are feeding upon decaying matter." This beetle is apparently the only serious enemy of the eggs, and its attacks on the eggs may be the result of straying from the normal habitat. Surely the escape of the eggs must involve the destruction of their enemy, either adults or young, for the presence of water in volume sufficient to sweep eggs and all out to sea must be a necessity. However this may be, either the beetle or the fish would seem to have made a mistake in its wanderings.

Two pods of eggs were taken with the larvæ of flies within them, and these larvæ were allowed to develop in the laboratory. In one case the pod had been dug up and reburied so that it is possible the fly concerned

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[1] This isopod was, through the courtesy of Waldo F. Schmitt, submitted to the United States National Museum for identification, and the following information obtained: "The isopod crustacean submitted is Tylos punctatus Holmes and Gay, described in 1909, type specimen from San Diego, California, with note 'burrows in sand.' This species is the only one of the Tylidæ so far recorded from the west coast of America, and there are but two specimens in the collections of the National Museum."

[2] We are under obligations to Dr. M. I. McCracken of Stanford University for quotations from the literature and reference of the specimens to Dr. E. C. Van Dyke for identification. Dr. E. C. Van Dyke states: "The beetles are specimens of Saprinus sulcifrons Lec., one of the Histeridæ, a family of steel-clad predaceous beetles which are generally to be found about dead animal and vegetable substances. * * * Most of the Histeridæ are more or less restricted in their habitat and general life history. Such is the case with the species sent by you. This is a sea coast species entirely, being widely distributed along the seashore of both Lower and Upper California. It is generally to be found under seaweed or old dead animals that are lying on the sand a little above the normal tide line. They are never to be found on the sand dunes back from the seacoast."

had laid its eggs while the pod was exposed. In the other case this could not have been true, the pod being exposed for the first time when the maggots were discovered. The two pods contained different species of flies, which have not been identified.

7. The Surrounding Conditions

But these natural enemies are obviously very few in number, and the greatest mortality would seem to be inevitably from physical causes. This would be dependent on the capacity of the eggs to withstand the variations in the environment. That they are able to withstand great changes in the salinity of their surroundings was easily ascertained by dropping the eggs in fresh water after the beating of the heart had become apparent. Eggs placed in tap water on the twenty-seventh of April were still alive on the fifth of May, although the heart beat was spasmodic. This was a period of eight days, and fully a week later than the normal hatching time of the eggs. The delay in hatching is not the result of the action of the fresh water, as will be seen later. Upon being placed in salt water one of these eggs hatched, although the larva proved incapable of movement. The larvæ from normally raised eggs (24 in number) placed in fresh water, died in the space of an hour (from 1.58 p.m. to 2.55 p.m. on the twenty-ninth of April), whereas their brothers in sea water lived for days. Evidently the egg capsules were efficacious in protecting the larvæ against such accidents as heavy rainfalls or freshets from the land.

However, the egg capsules seemed unable to protect the larvæ against desiccation, such as might ensue during days of great heat and consequent rapid evaporation. During the first days succeeding the tides the sand was fairly moist and firm—somewhat as it would be immediately after immersion in water and subsequent drainage, but ten or eleven days after the eggs were deposited the sand was exceedingly friable and on the surface completely dried out. The eggs were, however, in every case moist enough for life, and samples continued to exist in sand allowed to become much drier. To test the capacity to withstand such desiccation as might result from complete dryness, two dozen eggs were placed on a blotter and exposed to the air. These eggs were twelve days old, and well eyed. Placed upon the blotter at 3.38 p.m., the heart was still beating at 8.20 p.m., although the capsule was invaginated greatly, forming a cup. Shortly thereafter the beating of the heart ceased, the eggs appearing completely desiccated. Other eggs placed in a covered dish seemed to show no effects, moist atmosphere seemingly being sufficient. Still others, allowed to lie on the surface of the sand in closed bottles, existed for several days in the laboratory, and could not at the end of that time be distinguished from those which were buried. They are certainly not proof against evaporation, but are at the same time able to withstand as much as they would normally be exposed to on a beach. Even above the level of the highest tides the sand at a depth of four inches is always moist enough to enable the eggs to live. The danger from excessive evaporation does not seem very great.

But, perhaps, they might be compelled to undergo unusual temperature conditions. To ascertain what these were, a series of observations

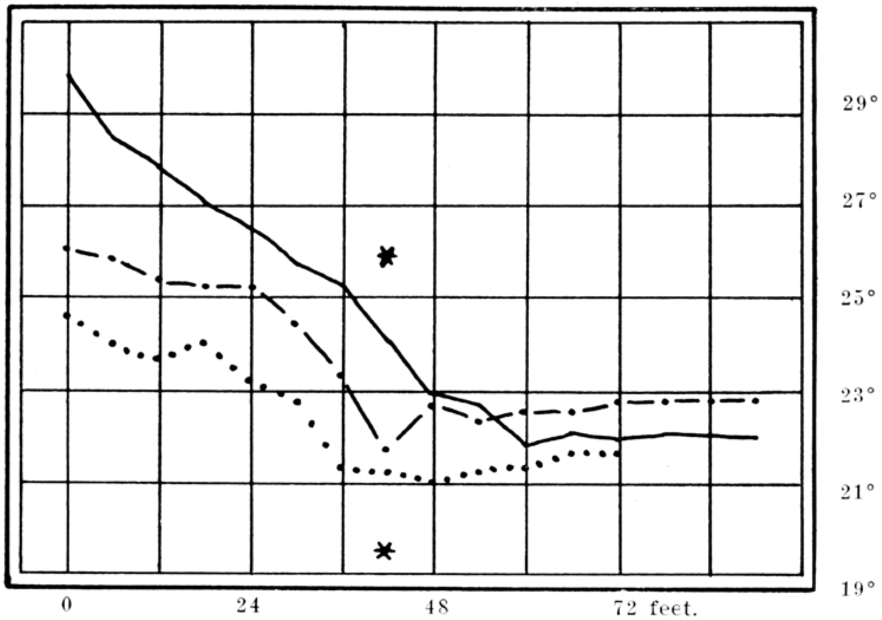

Fig. 3. Temperatures of beach across high tide line, the left of the figure the upper part of the beach, 6 p.m. April 20, 1919. Location of double line on Figure 2.★

*Fig. 3. Temperatures of beach across high tide line, the left of the figure the upper part of the beach, 6 p.m. April 20, 1919. Location of double line on Figure 2. **

were made at stations three feet apart across the beach on the twentieth of April, four days after the first eggs were laid. A thermometer, the usual chemical type with a bare bulb and stem, was thrust down into the sand, first just below the surface, then three inches down, and lastly six inches. The accompanying figure (Figure 3) shows the results of this, the left-hand side of the chart representing a distance of fifty-two feet above high tide line and the right-hand forty-eight below. The high tide line is the same as that shown in Figure 2. It will be noticed that the area occupied by the eggs was not markedly higher in temperature than that of the beach nearer the water, that at six inches down being actually less. Unfortunately the only thermometer then available broke shortly before the completion of the observations at a depth of six inches. The day was fair and warm, as is usual in southern California at the period of the year.

During the high tides beginning about May 13 two series of similar observations were made across the beach at stations three feet apart.

One of these series was made two hours after the high tide, which occurred at 9.06 p.m., and the other was made at 4.30 p.m. the next day. These should provide a contrast between the extremes of temperature which the eggs might meet with on such a day. In Figure 4 the two series are plotted. The space between the marks denoting the dry and the loose sand is the area within which the eggs, laid during the slightly higher subsequent tides, were expected to be. In Figure 5 the differences between the readings at each post are shown, revealing the rather surprising fact that at the three- and six-inch levels the fluctuation was greater near the line of loose sand than at any other part of the beach. It would seem from this observation that the eggs are laid in an area unfavorable in so far as evenness of

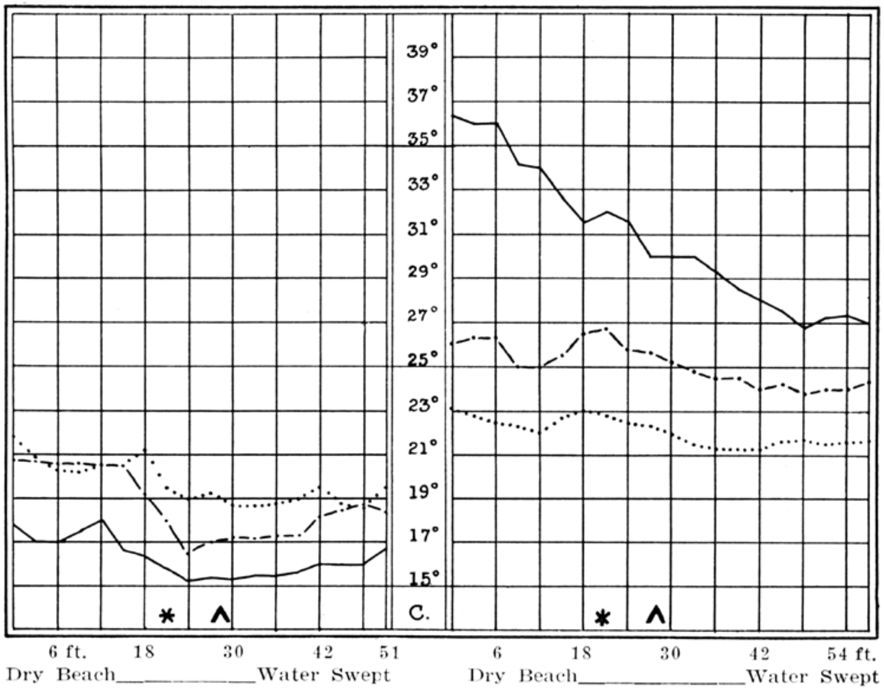

Fig. 4. Temperatures of beach across high tide line. Left hand of figure: 11 p.m. May 13, 1919. Air temperature 15.2° C. Water 17.9° C. Two hours after high tide of 5.6 feet. Right hand of figure: 4.30 p.m. May 14, 1919. Air temperature 18.5° C. Water 24.0°. Seven hours after high tide of 3.6 feet, seventeen hours after tide of 5.6 feet.

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temperature is desirable, although the depth in the sand avoids the great range of temperature found at the surface. In the spawning area there were, therefore, considerable variations in such conditions as temperature and amount of moisture present, to which the eggs were adapted. It would seem that a lower part of the beach would present more even conditions, but there is, as will shortly be seen, a very convincing reason in the mechanism of liberation against the utilization of such parts.

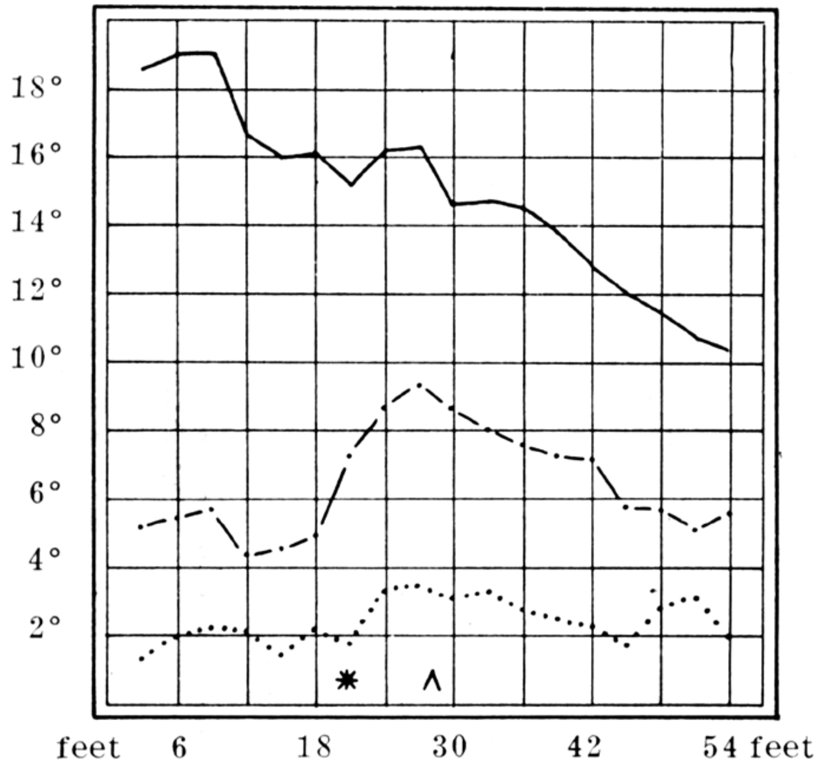

Fig. 5. Range in terperature between measurements of Figure 4, showing amount of fluctuation during one day across beach.

At surface: ————————

At 3 inches down: .———.———.

At 6 inches down: . . . .

Line of dry surface sand: ★

Line of loose sand: ∧ .

Fig. 5. Range in terperature between measurements of Figure 4, showing amount of fluctuation during one day across beach

8. The Escape of the Larvæ

When the pods of eggs were first found, there arose immediately the question of the manner of their escape. In order that direct evidence might be obtained as to this, five pods were dug up, placed in bags made of bobinette, with sufficient sand to weight the bags well, and reburied in the localities and depths from which they were taken. Another was reburied just before the following high tides. It was confidently expected that the eggs would work themselves free from sand, in the same manner in which they were separated from the sand in the laboratory. When eggs mixed with sand were placed in sea water and the whole agitated, the eggs, because of their specific gravity being less than that of the sand and more than that of the water, collected on top of the sand and could be picked off. Hence, the reburied eggs were expected to collect at the upper side of the bags. However, when the very high tides of the last of April had passed (see Figure 6), it was impossible to find all

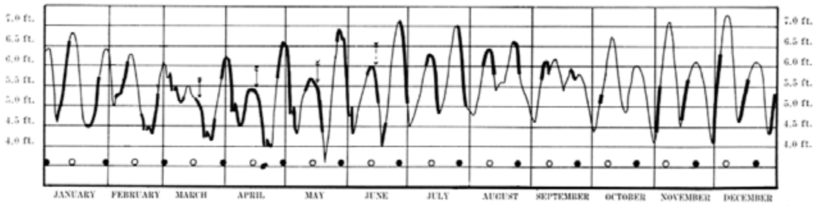

Fig. 6. Highest levels reached by tides each day at San Diego. Those occurring at night shown by heavy lines, those during the day by light lines. The phases of the moon indicated. The observed spawning times of *Leuresthes tenuis* indicated by arrows. Year 1919.

Fig. 6. Highest levels reached by tides each day at San Diego. Those occurring at night shown by heavy lines, those during the day by light lines. The phases of the moon indicated. The observed spawning times of Leuresthes tenuis indicated by arrows. Year 1919

the buried bags. Four of them had been swept out to sea, and in the other two, picked up during the height of the tide before they were swept out, the eggs were still at the bottom. To confirm these observations eggs were dug each day. They were obtained at the usual depth until the day after the first high tide had swept over them. Then they were found, still in their pods unmixed with sand, at a depth of an inch and a half or an inch and three-quarters. Plainly the presence of water more than sufficient to saturate the sand and seriously disturb it had proved unequal to the task of liberation. The following day, after another tide had swept over them, there were no eggs whatever to be obtained. The conclusion seems inevitable that the eggs, when they were liberated, were literally dug out of the sand.

This, of course, did not prove that this eroding action of the waves was invariable, and a sufficient means of escape. A direct observation of the action of the waves and tides was all that could settle such a question. To observe the action of a single tide, a double series of twelve posts were driven into the sand three feet apart across the beach from the highest point which the waves would be expected to reach.[1] These were driven in until their tops were thirteen centimeters above the sand. The position of the sand below these posts was read every fifteen minutes from 6.15 p.m. (7.15 p.m. summer time) to 10.15 p.m. (11.15 p.m. summer time), the time of high tide being about 8.10 p.m., and its height 5.6 feet, according to the United States Coast and Geodetic Survey tide tables for 1919. By calculating on the basis of the original height of the posts as a straight line, a cross section of the beach was made for each fifteen-minute interval. Table 6 and Table 7 give the data obtained, and in Figure 7 these are shown graphically for one of the series of posts. The erosion is shown in stipple, while the deposited sand, as well as the finally replaced sand, is shown in black. In order to give a record of the progress of the tide, the average post reached by six successive waves during each time interval is shown by the circles. It will be seen that there was a well-marked area in which the waves deposited sand, and another in which erosion predominated. There was, as a result, a gradual encroachment of the eroded area until the height of the tide had passed, while sand was deposited at a higher level. As the tide receded the deposited sand was left and the eroded area was partially refilled. There is, therefore, an area of erosion, and a depositing lip, as one may term it.

The area of erosion is characterized by a steep slope, and by gullies, sometimes six or eight inches deep. It may therefore be easily distinguished,

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[1] These observations were made in conjunction with Professor F. W. Weymouth of Stanford University, who was interested because of the possible bearing of the phenomenon on the clams and crabs he was engaged in studying for the Fish and Game Commission.

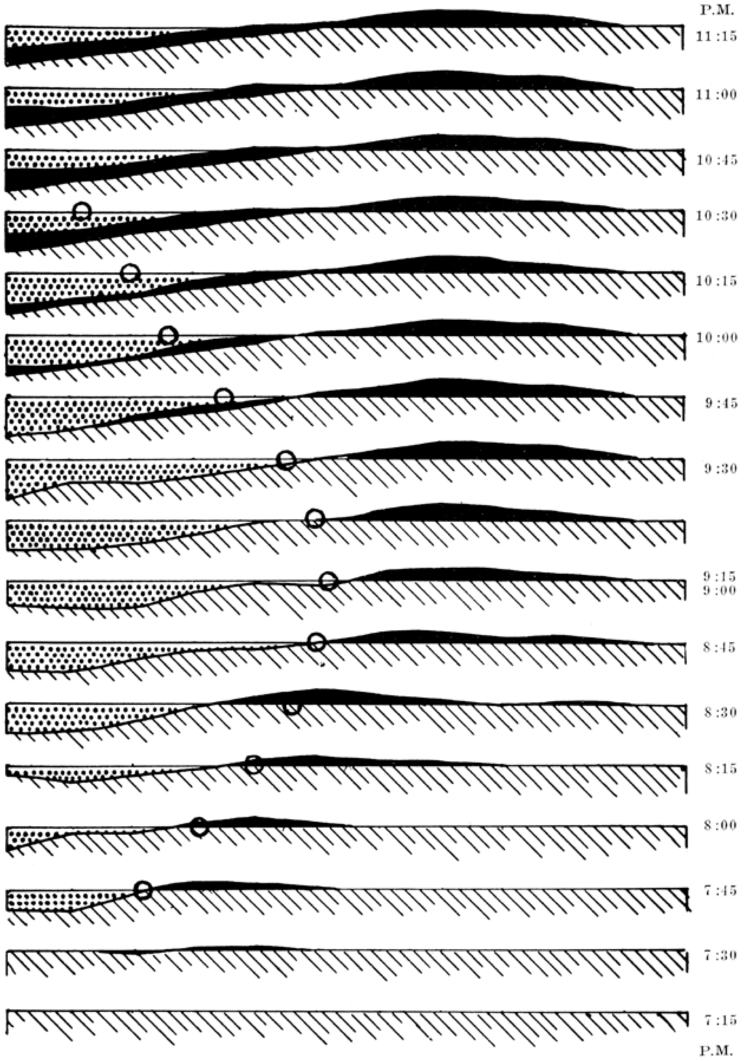

Fig. 7. A series of cross-sections of the beach, the ocean on the left-hand side, to show erosion and replacement by the tides. Taken at fifteen-minute intervals during a high tide of 5.6 feet on May 13, 1919, at Long Beach. Erosion indicated by dotted area, deposited or refilled sand by solid black, and average extent of wave wash by circles. Basis of measurement, the profile of the beach before the tide, shown as a straight line at 7:15 (summer time).

Fig. 7. A series of cross-sections of the beach, the ocean on the left-hand side, to show erosion and replacement by the tides. Taken at fifteen-minute intervals during a high tide of 5.6 feet on May 13, 1919, at Long Beach. Erosion indicated by dotted area, deposited or refilled sand by solid black, and average extent of wave wash by circles. Basis of measurement, the profile of the beach before the tide, shown as a straight line at 7:15 (summer time)

and its invariable presence demonstrated by observation. The process may easily be seen to depend on the carrying power of the water swept up the beach by each wave. The initial rush upward of sand-filled water is stopped by the slope of the beach so that the sand is dropped; then the water runs down the slope gathering carrying power as it goes and increasing in quantity, until, when it reaches the eroding area, it is capable of lifting and carrying away the sand it brought, and more. The coarser the sand, the steeper the slope necessary to give the water the speed required to carry the sand and the narrower the resultant beach. The steep slope of the eroded area in fact prevents a pause of the water for a sufficient time to allow the sand it carries to be dropped before the current is reversed strongly. Upon this process of erosion the grunion depends for its escape from the sands and therefore for its existence.

But this conclusion could hold only if the larvæ are incapable of aiding their own escape, and the question arises as to what condition the eggs are in when they are liberated. Does hatching take place before or after? This question received an unexpected and convincing answer. Samples were collected daily for the purpose of obtaining the various stages of development of the fish, and when brought into the laboratory the eggs were separated from the sand by agitating in salt water. On the twenty-sixth of April, ten days after the first day of the preceding spawning, and one day before the first of the succeeding high tides, a large part of the samples taken from the beach hatched while being handled, four or five minutes after being placed in salt water. The samples, five in number, collected the succeeding day, hatched to the last fertile egg after a similar period of exposure to salt water. That they were ready for their scheduled escape could not be gainsaid. The eggs, washed out of the sand by its erosion, immediately hatch, and the vigorous larvæ are free to escape into the surf. The period of development is adapted to the tides.

However, if the larvæ are thus ready for their escape, it is possible that when the sand around them is moistened and lightened, they can hatch and make their own way into the open water. The truth of this was easily determined, by placing a pod with its surrounding sand in a dish and flooding it with water. There were a number of eggs—perhaps 30 per cent of the total—which were left on the surface of the sand. These were picked off and placed in a separate dish, where they quickly hatched. of the others, one lot, buried in the sand, was left over night, then separated from the sand. None hatched before being freed. Another lot, left an hour buried in wet sand, hatched only when released from the sand. In still another lot, small numbers of eggs were freed at intervals, when they hatched; but those buried awaited their liberation. The eggs in all these cases were frequently visible among the grains of sand, being but partially buried. The experiments were repeated many times in the process of preserving samples of eggs, with the same results each time. Complete freeing was necessary, the larvæ not aiding their own escape in any way whatsoever. In other words, they were completely dependent on the action of the waves for their existence.

9. The Adaptation of the Spawning to Physical Phenomena

Knowing these conditions under which the eggs live and are liberated, it is possible to return to a consideration of the conditions under which they are laid, and the adaptations made to meet the circumstances. A consideration of the runs in relation to the waves; to the individual tide; to those of succeeding days; to the series of tides accompanying the phases of the moon; and to the season, will be taken up in order and will bring out the details.

The habit of the fish of running in with the highest waves is plainly adapted to allow them to reach the area in which the sand is being deposited. The females caught were invariably laying their eggs at the upper edge of the eroded area, where the sand was soft and easily penetrated. To reach this during either the full or the ebbing tide, the heavier waves were necessarily utilized. If the eggs had been laid at a lower level the same or succeeding tides would have swept them away. Laid where they were, the sand was actually deposited over them, and in this circumstance is found the explanation of the discrepancy between the depth at which the pods were found and the size of the female. But the certainty of being swept out to sea also existed if the earlier parts of the tides were used. The eggs, buried in the upper edge of the area of erosion, would be unearthed by its advance. However, it has been repeatedly observed by the writer and others—indeed it is common knowledge—that the run does not begin until the tide has reached its height, and continues during the first stages of its ebb. Observations thus far made by the writer show that the run lasts about an hour, beginning near the time of high tide. This is given in the following table, showing the approximate duration and times of the runs of the grunion.

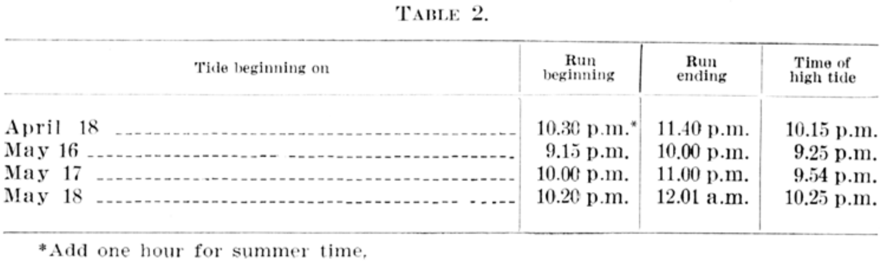

TABLE 2.

Tide beginning on	Run beginning	Run ending	Time of high tide
April 18	10.30 p.m.*	11.40 p.m.	10.15 p.m.
May 16	9.15 p.m.	10.00 p.m.	9.25 p.m.
May 17	10.00 p.m.	11.00 p.m.	9.54 p.m.
May 18	10.20 p.m.	12.01 a.m.	10.25 p.m.

*Add one hour for summer time.

TABLE 2

The data given in this table are, however, somewhat unreliable. The runs were not at all continuous, and were found to be made up of various small runs, some of which came in on but parts of the beach, making it extremely difficult to be sure that all were observed. Furthermore, isolated pairs were observed to come in long after the larger schools seemed to have departed. That the times given are approximately correct was judged by the actions of the crowds of "fishermen," who were thrown into great activity by the start of the run and departed upon its conclusion. In general, it may be said that the runs began about the turn of the tide and continued for about an hour. This allowed the depositing of the eggs when the eroding area had reached its greatest extent (see Figure 7) and in a region which would not be reached by it in succeeding tides. Eggs laid an hour too early would have been laid at too low a level and would have been washed out; while eggs laid two or three hours after the tide had turned might also have been laid too low and have been washed out by the succeeding tide. That the period of each run is thus approximately timed admits of no doubt, however difficult it may be to explain the exquisite nicety of the adaptation.

But adaptation must also have a relation to the varying height of the tides from day to day, as well as to the height of the individual tide. It would avail little to have the eggs laid where succeeding tides would wash them away during the extension of the eroded area. Just as the spawning must occur at that stage of the individual tide at which the ebb commences, so must the spawning runs occur at those times when the succeeding tides become lower. The highest tides occur at about the full, or the dark of the moon, hence these lower tides *follow* the full of the moon, or the dark.

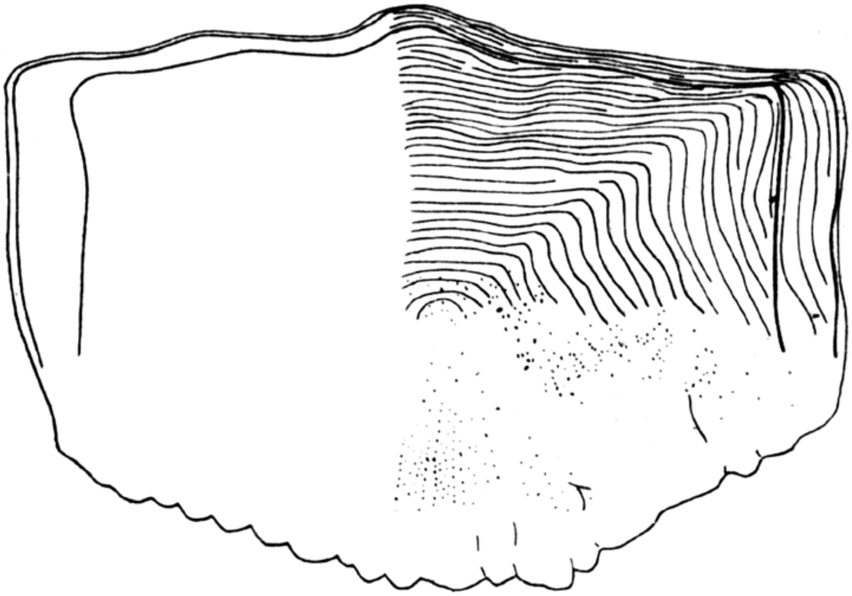

Fig. 8. Scale of *Leuresthes tenuis*, the Grunion. Female 17.1 cm. long taken April 17, 1919, at Long Beach, California. Showing what seems to be two winter marks, one of which is at the very edge.

Fig. 8. Scale of Leuresthes tenuis, the Grunion. Female 17.1 cm. long taken April 17, 1919, at Long Beach, California. Showing what seems to be two winter marks, one of which is at the very edge

And in the adaptation to this sequence of the tides, is seen the explanation of the fact that the runs occur after the full moon. Mr. Joplin said: "On the second, third, and fourth nights after the full moon." However, in so far as the present limited observations go, this is only approximately correct. Thus the moon was full April 15, at 8.25 a.m., Greenwich mean civil time, or about 12.30 a.m. our local time. The fish began to run April 16 at 9.28 p.m. (10.28 p.m. summer time), therefore the second night, and the second tide of the series after the full moon. Again, the moon was full May 15, at 1.01 a.m. Greenwich mean civil time, or May 14, at about 5.00 p.m. local time, whereas the grunion ran at 9.25 p.m. (10.25 p.m. summer time) on the sixteenth. This was the third night, and the third high tide of the series after the full of the moon. In both cases the grunion ran on the sixteenth, seventeenth, and eighteenth, three days. Therefore, probably the only exact statement which can be made is that the spawning runs come shortly *after* the full of the moon, in other words *after the highest tide* of the series, which is the really significant fact. The popular saying is merely an attempt to state exactly a very remarkable fact.

To illustrate the varying effect of the advancing and receding tides of a series, measurements of the depth of the sand were taken along a line of posts transverse to the beach, and also along a line parallel to the beach. The former were at three-foot intervals, post 1 being above high tide. The results are shown in Table 3. Measurements were taken at

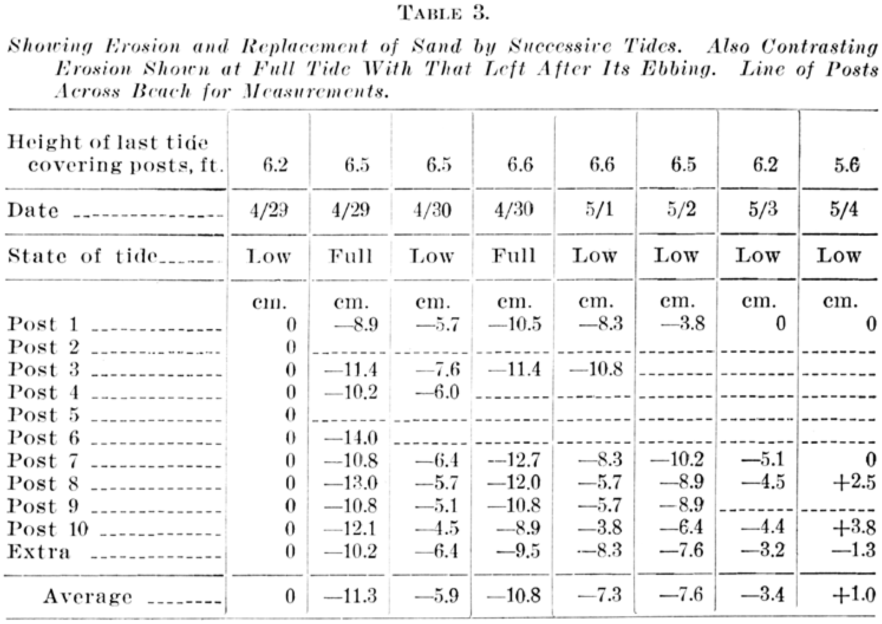

TABLE 3.

Showing Erosion and Replacement of Sand by Successive Tides. Also Contrasting Erosion Shown at Full Tide With That Left After Its Ebbing. Line of Posts Across Beach for Measurements.

Height of last tide covering posts, ft.	6.2	6.5	6.5	6.6	6.6	6.5	6.2	5.6
Date	4/29	4/29	4/30	4/30	5/1	5/2	5/3	5/4
State of tide	Low	Full	Low	Full	Low	Low	Low	Low
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Post 1	0	—8.9	—5.7	—10.5	—8.3	—3.8	0	0
Post 2	0	--------	--------	--------	--------	--------	--------	--------
Post 3	0	—11.4	—7.6	—11.4	—10.8	--------	--------	--------
Post 4	0	—10.2	—6.0	--------	--------	--------	--------	--------
Post 5	0	--------	--------	--------	--------	--------	--------	--------
Post 6	0	—14.0	--------	--------	--------	--------	--------	--------
Post 7	0	—10.8	—6.4	—12.7	—8.3	—10.2	—5.1	0
Post 8	0	—13.0	—5.7	—12.0	—5.7	—8.9	—4.5	+2.5
Post 9	0	—10.8	—5.1	—10.8	—5.7	—8.9	--------	--------
Post 10	0	—12.1	—4.5	—8.9	—3.8	—6.4	—4.4	+3.8
Extra	0	—10.2	—6.4	—9.5	—8.3	—7.6	—3.2	—1.3
Average	0	—11.3	—5.9	—10.8	—7.3	—7.6	—3.4	+1.0

TABLE 3.

Showing Erosion and Replacement of Sand by Successive Tides. Also Contrasting Erosion Shown at Full Tide With That Left After Its Ebbing. Line of Posts Across Beach for Measurements.

full tide, when the waves were washing over the posts, and at low tide, when the posts were dry. There was always a certain amount of replacement of sand by the ebbing tide, as for instance is shown by the average erosion of 11.3 centimeters (4.5 inches) by the tide on the twenty-ninth, and its replacement to a depth of 5.9 centimeters, as shown by measurements next day. The last tide which reached the posts, as measured on the fourth, had almost entirely replaced the eroded sand. It will be noted that an average of 11.3 centimeters was reached on the twenty-ninth, which was a depth equal to or exceeding the depth to which the eggs had been buried, and if more care had been taken to find the maximum, a very much higher average would have been attained. Unfortunately several of the posts were swept away, although 50 centimeters in length. A similar erosion and replacement was shown by a line of posts parallel to the beach, but distant about fifteen feet from each other. (See Table 4.) These posts, which were remnants of an old breakwater, were not placed low enough on the beach to show the

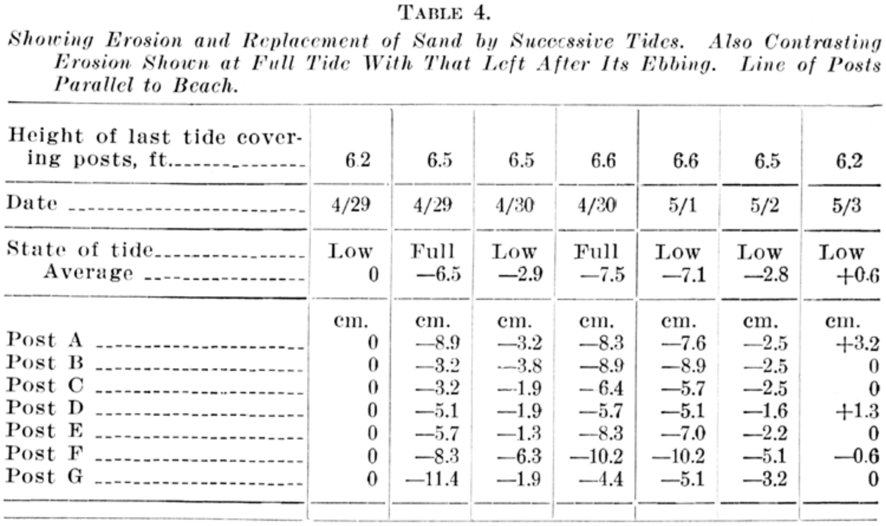
TABLE 4.

Showing Erosion and Replacement of Sand by Successive Tides. Also Contrasting Erosion Shown at Full Tide With That Left After Its Ebbing. Line of Posts Parallel to Beach.

Height of last tide covering posts, ft.	6.2	6.5	6.5	6.6	6.6	6.5	6.2
Date	4/29	4/29	4/30	4/30	5/1	5/2	5/3
State of tide	Low	Full	Low	Full	Low	Low	Low
Average	0	—6.5	—2.9	—7.5	—7.1	—2.8	+0.6
	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Post A	0	—8.9	—3.2	—8.3	—7.6	—2.5	+3.2
Post B	0	—3.2	—3.8	—8.9	—8.9	—2.5	0
Post C	0	—3.2	—1.9	— 6.4	—5.7	—2.5	0
Post D	0	—5.1	—1.9	—5.7	—5.1	—1.6	+1.3
Post E	0	—5.7	—1.3	—8.3	—7.0	—2.2	0
Post F	0	—8.3	—6.3	—10.2	—10.2	—5.1	—0.6
Post G	0	—11.4	—1.9	—4.4	—5.1	—3.2	0

TABLE 4.

Showing Erosion and Replacement of Sand by Successive Tides. Also Contrasting Erosion Shown at Full Tide With That Left After Its Ebbing. Line of Posts Parallel to Beach.

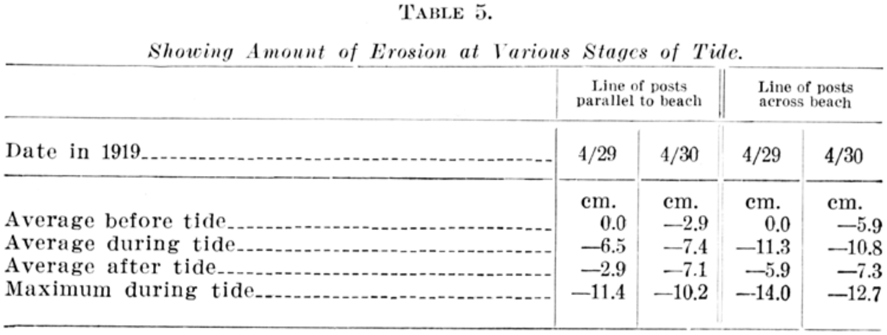
TABLE 5.

Showing Amount of Erosion at Various Stages of Tide.

	Line of posts parallel to beach		Line of posts across beach	
Date in 1919	4/29	4/30	4/29	4/30
	cm.	cm.	cm.	cm.
Average before tide	0.0	—2.9	0.0	—5.9
Average during tide	—6.5	—7.4	—11.3	—10.8
Average after tide	—2.9	—7.1	—5.9	—7.3
Maximum during tide	—11.4	—10.2	—14.0	—12.7

TABLE 5.

Showing Amount of Erosion at Various Stages of Tide.

erosion to its full extent, but the measurements obtained illustrate and corroborate the facts brought out by the other series. To bring these together in a more striking fashion, the data have been placed in Table 5. The phenomenon of erosion and replacement is obvious from these measurements, the extent naturally varying according to the weather and the resultant size of the waves, which were small at the time.

We may therefore conclude with some assurance that the eggs of the grunion are laid at times which allow them to escape the great danger of coming within the area of advancing erosion, and it is clear why the coming of the spawning runs subsequent to the highest tides of a series should serve the survival of the species.

But this does not conclude the matter. For, furthermore, the utilization of the tides during the full of the moon means the use of the lower series of tides which occur during the spawning period. The tides accompanying the dark of the moon are all very much higher (see Figure 6) and carry the area of erosion much farther up the beach, therefore uncovering all the pods left under the deposited sand by the preceding lower series. This occurs two weeks after the spawning at the precise time when the eggs are ready to hatch, and is clearly highly advantageous to the species.

The explanation of the apparent failure to make use of the higher series of tides for spawning may exist in the fact that eggs laid during one of the higher series might not be reached for a month or more by following tides, and then only with the sand depositing lip shown in Figure 7. In Figure 6 the greatest height reached daily is shown for each series of tides, and an alternation of lower series during the full moon with a higher series during the dark of the moon is to be observed during March, April, May, June, and July. Eggs laid during the dark of the moon would therefore risk lying in the sand for the time elapsing between the higher series, at least a month, and in May or June they might be left for a full year because of the habit of laying the eggs very near the upper limit reached by the waves. But in so far as personal observations show, there are no runs during the dark of the moon. Only during the tides when it is full are the eggs laid. The high tides of the last of April were observed with this in view, but not a single grunion was found on the beach, despite the fact that the preceding and the succeeding tides, during the full moon, were characterized by abundant runs. This corroborates in part the words of Mr. Joplin previously quoted: "On the second, third, and fourth nights *after the full moon*." Hearsay evidence was obtained in one case concerning fish taken at the dark of the moon, but as it would not bear critical examination, it could not well be accepted. In so far as actual observation is concerned, then, the fish run only during the full moon, and until further proof of runs during other periods is obtained this conclusion should hold. It is, as it now stands, a very remarkable one, implying as it does a migration discriminating between series of tides.

There seems no obvious reason, however, why eggs could not be laid during the tides coming in the dark of the moon, if the run should be during a very late part, when the series was receding and the eggs could be laid where the eroding area of the succeeding lower series (ten days later) could reach them. If they were laid at a higher level they would, as has been observed, be compelled to await the tides of a month later, or perhaps, if laid in May or June, fail altogether of liberation. They would thus be exposed to a much greater danger of falling prey to terrestrial enemies, because of the much longer incubating period, and the greater accessibility to those enemies of the higher part of the beach. The temperature changes and the extent of evaporation in the surrounding sand would also be very much greater. But if laid at a low level, there would in reality be but a single tide of the series in which this could be done, because of the greater rapidity of the fall. Although it is not very obvious why this opportunity should not be utilized, nor indeed is there absolute proof on hand that it is not, yet it is plain that the runs occur for the greater part during the most advantageous tides.[*] These facts, even so far as we are able to state them confidently, are remarkable instances of adaptation, and habits altered to fit the varying character of the tides more closely than is at present obvious would be not less, but more remarkable.

Such adaptations may be possible only during a certain season of the year, for the tides seem capable of accommodating such habits only during the months between March and July inclusive. To show the

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[*] Since writing the above, grunion were taken in small numbers during the tides beginning on the first and second of June.

The dark of the moon occurred on the twenty-ninth of May. On that night, and on the thirtieth and thirty-first of May, careful watch was kept over a mile and a half of beach for a period of an hour and a half after the scheduled time of high tide; but no sign of grunion was seen. The tide on the twenty-ninth of May was 6.7 feet at San Diego, the point of reference for our locality; on the thirtieth, 6.7 feet; on the thirty-first, 6.3 feet; on the first and second of June (when the grunion were taken), 5.7 feet and 5.0 feet, respectively. The latter two tides approximated the height of the tides at the full of the moon, which were 5.4 feet on April 16; 5.7 feet on May 14; and are predicted by the United States Coast and Geodetic Survey as 6.0 feet on June 13. The tide on the first of June, of 5.7 feet, was therefore the one during which a run of grunion could have been expected, according to our reasoning, and the eggs laid at that time will probably be freed as larvæ by the next full moon tides.

However, the number of grunion observed was very small. The fish were seen at 12.30 a.m. and at 12.40 a.m. during the tide commencing June 1 on two different parts of the beach, and in each case but a single small school was observed. During the tide commencing June 2, but four scattered individuals were seen at the very height of the tide, despite prolonged search. It is perfectly possible that such small runs could escape attention and caution must therefore be used in concluding that no fish spawn on the other tides during the dark of the moon. This does not seem probable, aside from our direct observations, for during the earlier tides of each series the beach is as a rule occupied by people passing or having beach parties, and any run of fish would be quickly noticed and the news spread. The conclusion that the main run *does* occur during the full of the moon seems therefore entirely probable possible reason for this, Figure 6 has been drawn. As has been previously mentioned, the highest tides on each day are shown on the chart, those coming after nightfall being indicated by a very heavy line, those coming during the day by a light line. The grunion, coming in to spawn on wide sandy beaches, would be supposedly the natural prey of many enemies such as sea gulls if the run occurred during the day, and in their utilization of night tides they may have become adapted to meet this circumstances. If so, the tides used must not only be the receding ones in each series, but must also come at night. Such tides are peculiar to the months, March to August, inclusive.

The validity of this reasoning is, however, open to some question, as it is very difficult to prove that daylight spawning is impractical. Even though no such reason exists, the fact that the spring months are the natural spawning months of other species of smelts (Atherinoids) as well as of many other species of fish, predisposes the observer to conclude that such might have been the season for the grunion from the beginning. If so, the use of the receding tides to avoid the eroding of the advancing tides would require use of night tides at that season. That such is probably advantageous is evident enough, however. It will suffice, then, to conclude that the season utilized by the grunion is remarkably well adapted to its purposes.

Reasoning in regard to the mechanism of the adaptation of the grunion to the tidal action is plainly enough a futile task. The migrating impulse does not arise in response to the light of the moon, for during the last spawning run in May, heavy clouds obscured the moon through each night. Beyond this no data are at hand to utilize in speculation.

10. Imperfections in Adaptation

The perfection of these adaptations, or in other words, the invariable success of the spawning is open to serious question. An example of an imperfection was found in the spawning run of May 16 to 18. The eggs were laid during calm weather, when the waves washed up the beach less than is usually the case, and the spawning therefore occurred low on the beach, especially on the eighteenth. But on the nineteenth to the twenty-second heavy swells prevailed and the area of erosion rose farther up the beach than the area in which the eggs were laid, as was ascertained by measurement from fixed posts. The consequences were what might have been expected, that very few eggs from the spawning on the eighteenth remained in the sand, a fact proved by extensive digging. This did not, of course, mean the actual destruction of the eggs, in so far as present knowledge goes, but did mean that whatever advantage the grunion gained in the protection of its eggs was partially lost, and that they were forced to endure the same rate of mortality that fish with less perfected habits but far greater fecundity undergo. The eggs of the grunion, few in number, are obviously far less able to survive the energetic attacks of the multifarious enemies which might prey on them in the open sea than the eggs of such fish as the cod, numbering into the millions.

Such deviations from the average course of events must be disastrous to the eggs of the grunion, the more so the more precise the act of spawning required to fit into the natural phenomena concerned. Thus the spawning of the grunion during the dark of the moon might necessitate a run on a single night, and a marked deviation in the tides either on that night or the following would prove destructive in the extreme. The spawning run at the full of the moon occurs two or three days after the approximately greatest height of the tide has been reached, and just previous to the sharp fall in height of the series. This timing of the runs eliminates, of course, the danger of unusual fluctuations during several tides of nearly equal height, when a strong wind might carry the waves excessively high and hence sweep out to sea all the deposited eggs. In other words, the lateness of the run during the series of tides, in losing the use of the series of nearly equal highest tides (sometimes four or five in number), also avoids the danger that an unusual height in the last of them would destroy the deposited eggs. It is plain that such great natural fluctuations are the greatest enemies the grunion eggs must meet, being to them in the nature of catastrophes, and the timing of the runs appears to be an adaptation to meet them.

But the grunion egg is not without ability to survive one type of natural "catastrophe." That it is subject to being washed out to sea is easily understood, and the reverse of that, a failure to be liberated at the proper time, would seem to be expected occasionally, especially if the eggs are laid at an unusual distance up the beach, and are covered too deeply by the deposited sand. To test their ability to withstand burial for a month, five pods of eggs were dug out of the beach on the twentieth of April, kept until after the spawning runs in May, then washed out of the sand. These eggs were laid in the runs on the sixteenth, seventeenth, and eighteenth of April, hence were five days more than a month old; but a large percentage hatched (respectively, 10 per cent; 30 per cent; 30 per cent; 50 per cent; 20 per cent). These larvæ were all ready for hatching on the twenty-eighth of April, as was ascertained by hatching some from each lot. The larvæ of the grunion, therefore, after reaching the proper stage for hatching, are capable of lying quiescent in their capsules for fully two weeks, awaiting the proper conditions under which they may escape. This is an unusual phenomenon, perhaps something which no other species is known to be capable of.

At the same time, this halt in the normal development is made at great expense. The larvæ which hatched when first ready—in time for the first high tides after spawning—gave a very high percentage of swimming young, while those kept for a prolonged period gave a very much lower one. The delayed larvæ were also very much less vigorous, hatching out slowly during a period of three-quarters of an hour, whereas four minutes sufficed for the normally released larvæ to escape. It is impossible to avoid the conclusion that a prolongation of the egg stage is highly injurious, and surely results in the failure of a great many of the young to survive. In this must be found one of the disastrous results avoided by the habit of spawning during the full moon tides and not during the higher tides of the dark of the moon. Eggs laid during the full moon tides would be liberated in two weeks by the succeeding very high tides, whereas those laid during the dark of the moon at the height of the tides, would be compelled to await the tides a month later, with the added danger that even those might not reach them.

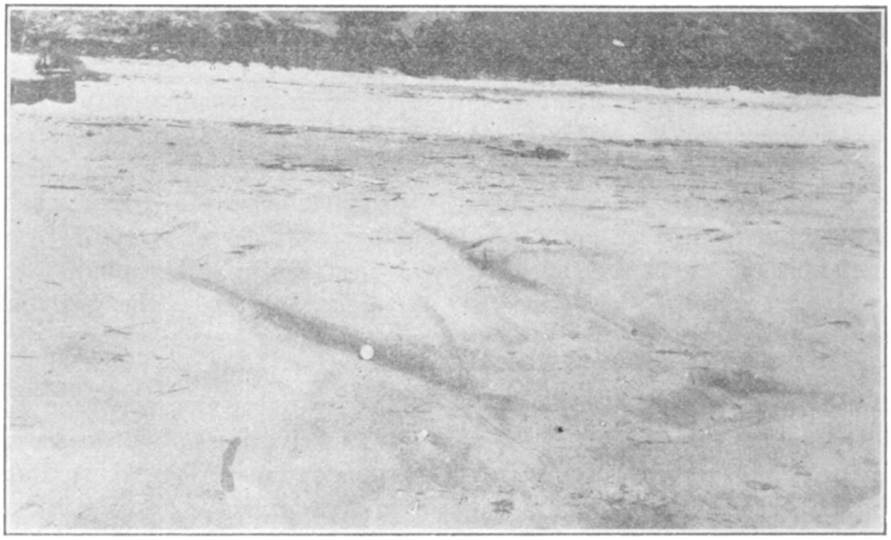

Fig. 9. Beach showing erosion of sand by gullies, at Long Beach, May 23, 1919. The tide at the dark of the moon has left debris near the foot of the cliff, while that at the full of the moon has left the line of debris along the edge of the dark (moist) sand, above the area of erosion.

Fig. 9. Beach showing erosion of sand by gullies, at Long Beach, May 23, 1919. The tide at the dark of the moon has left debris near the foot of the cliff, while that at the full of the moon has left the line of debris along the edge of the dark (moist) sand, above the area of erosion

The story concluded by the escape of the larvæ into the surf comprises one of the most marvelous of the many strange chapters in the life histories of fish. It is eloquent of exquisite adaptations to a seemingly minor physical phenomenon—the erosion of the beach by one part of a wave, and its upbuilding by another. Those waves are made use of which carry the fish high on the beach; those parts of the tide are utilized which allow the pods of eggs to be laid without risk that further rise of the tide will carry the eroded area over them; the runs occur during those tides in a series which are the last available, because of their height, thus eliminating in so far as possible the danger that unusually rough weather will sweep away the eggs; and the eggs are laid during those series of tides which will allow of the escape of the larvæ two weeks later. The larvæ themselves do not hatch until the sand over them is swept away, even though a month pass by; but when the time comes and the waves of the high tides wash over them, eroding the surrounding sand, they are ready to escape. The eggs are laid in what is nearly dry land, or moist soil, a fact which has no parallel in our knowledge of marine fishes. They are subject to attack by terrestrial enemies, but escape the far more numerous marine enemies. Indeed, so advantageous to the species are these adaptations that the female lays thousands of eggs where millions are laid by other forms. But perhaps the most remarkable fact is the dependence of the existence of a species on a phenomenon so unobtrusive as the shifting of the sand on the seashore.

TABLE 6.

Series of Measurements of Height of Fixed Posts Set at Three-Foot Intervals Across Beach, Parallel to Posts of Table 7, to Show Erosion and Replacement by the Tide. Taken at Fifteen-Minute Intervals During a High Tide of 5.6 Feet on May 13, 1919, at Long Beach. The Deviation of the Tops of the Posts From a Straight Line Given in Table 8.

SERIES A.

	1	2	3	4	5	6	7	8	9	10	11	12
7.15 ------	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
7.30 ------	13.0	13.0	13.0	13.0	13.0	13.0	13.0	12.4	12.8	13.7	13.2	13.5
7.45 ------	13.0	13.0	13.0	13.0	13.0	13.0	12.9	12.2	12.0	13.6	16.8	16.5
8.00 ------	13.0	13.0	13.0	13.0	13.0	13.0	12.5	11.5	12.5	14.0	14.0	16.4
8.15 ------	13.0	13.0	13.0	13.0	12.7	12.5	11.6	12.0	13.7	14.5	15.5	14.5
8.30 ------	13.0	13.0	12.8	12.9	12.3	11.8	10.6	12.0	13.5	15.3	17.2	17.7
8.45 ------	13.0	13.0	12.1	12.3	11.5	11.6	13.0	14.0	14.1	15.8	17.4	17.3
9.00 ------	13.0	12.9	12.0	11.9	11.0	11.7	13.7	13.3	14.8	17.1	17.2	16.8
9.15 ------	13.0	12.9	12.0	11.5	10.6	11.5	12.9	13.6	15.3	16.8	17.7	17.6
9.30 ------	13.0	12.9	11.5	10.9	10.3	11.6	13.0	14.4	15.6	17.0	16.8	19.7
9.45 ------	13.1	12.7	11.5	11.0	10.3	11.6	12.6	14.0	14.6	16.4	18.0	19.6
10.00 ------	13.1	13.0	11.7	11.2	10.5	11.9	12.7	13.4	14.0	16.7	17.5	18.0
10.15 ------	13.1	13.0	11.8	11.2	10.5	11.8	12.6	12.9	14.4	16.4	17.2	18.1
10.30 ------	13.2	13.0	11.6	11.2	10.5	11.8	12.6	12.5	13.7	15.0	16.5	16.8
10.45 ------	13.2	13.0	11.6	11.1	10.5	11.8	12.6	12.6	13.7	15.1	16.0	16.1
11.00 ------	13.2	13.0	11.6	11.1	10.6	11.8	12.5	12.5	13.6	15.0	16.1	16.3
11.15 ------	13.2	13.0	11.6	11.1	10.6	11.8	12.5	12.5	13.6	15.0	15.9	16.3

TABLE 6.

Series of Measurements of Height of Fixed Posts Set at Three-Foot Intervals Across Beach, Parallel to Posts of Table 7, to Show Erosion and Replacement by the Tide. Taken at Fifteen-Minute Intervals During a High Tide of 5.6 Feet on May 13, 1919, at Long Beach. The Deviation of the Tops of the Posts From a Straight Line Given in Table 8.

TABLE 7.

Series of Measurements of Fixed Posts Similar and Parallel to Those of Table 6. This Differs From That of Table 6 in Presence of Gully From Post 6 Outward.

SERIES B.

	1	2	3	4	5	6	7	8	9	10	11	12
7.15 ------	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
7.30 ------	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	11.8	12.0
7.45 ------	13.0	13.0	13.0	13.0	13.0	12.8	12.3	12.1	12.9	13.0	14.0	15.9
8.00 ------	13.0	13.0	13.0	13.0	13.0	12.7	12.2	11.4	12.0	15.0	14.2	13.8
8.15 ------	13.0	13.0	13.0	12.8	12.9	12.7	11.6	11.6	13.7	15.2	17.0	14.3
8.30 ------	13.0	13.0	13.0	12.5	12.6	12.4	11.0	12.8	15.0	18.8	17.3	17.0
8.45 ------	13.0	13.0	13.0	12.3	12.0	11.6	11.0	13.6	17.3	17.9	17.0	16.0
9.00 ------	13.0	12.8	12.1	11.2	11.0	12.1	12.5	17.2	17.6	19.6	18.2	15.7
9.15 ------	13.0	12.6	11.8	10.6	10.5	12.2	15.8	16.7	17.9	17.3	17.2	20.0
9.30 ------	13.0	12.5	11.5	10.0	10.5	13.3	19.2	19.0	19.3	20.0	20.1	17.3
9.45 ------	13.1	12.4	11.2	9.8	10.5	13.8	17.0	18.1	19.1	20.6	20.9	19.8
10.00 ------	13.2	12.6	11.3	9.9	10.5	13.9	16.8	16.8	18.1	19.2	19.7	18.3
10.15 ------	13.3	12.4	11.3	9.8	10.7	14.8	17.3	16.8	18.5	19.8	20.0	18.0
10.30 ------	13.2	12.6	11.2	9.8	10.6	14.5	17.1	16.5	18.1	19.3	18.8	17.6
10.45 ------	13.3	12.6	11.2	9.8	10.6	14.6	17.0	16.6	18.1	19.0	18.1	17.2
11.00 ------	13.3	12.6	11.2	9.8	10.7	14.8	17.0	16.5	18.2	19.0	18.3	17.5
11.15 ------	13.3	12.6	11.2	9.8	10.7	14.8	17.0	16.5	18.2	18.9	18.3	17.2

TABLE 7.

Series of Measurements of Fixed Posts Similar and Parallel to Those of Table 6. This Differs From That of Table 6 in Presence of Gully From Post 6 Outward.

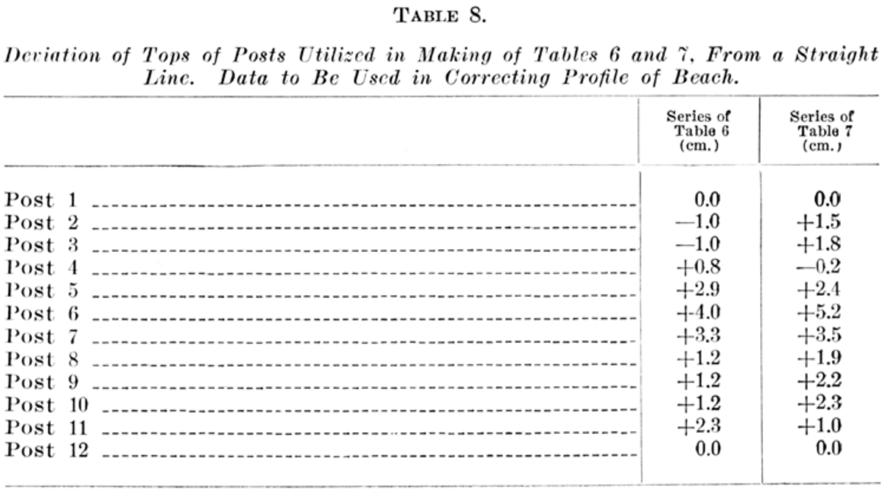

TABLE 8.

Deviation of Tops of Posts Utilized in Making of Tables 6 and 7, From a Straight Line. Data to Be Used in Correcting Profile of Beach.

	Series of Table 6 (cm.)	Series of Table 7 (cm.)
Post 1	0.0	0.0
Post 2	—1.0	+1.5
Post 3	—1.0	+1.8
Post 4	+0.8	—0.2
Post 5	+2.9	+2.4
Post 6	+4.0	+5.2
Post 7	+3.3	+3.5
Post 8	+1.2	+1.9
Post 9	+1.2	+2.2
Post 10	+1.2	+2.3
Post 11	+2.3	+1.0
Post 12	0.0	0.0

TABLE 8.

Deviation of Tops of Posts Utilized in Making of Tables 6 and 7, From a Straight Line. Data to Be Used in Correcting Profile of Beach.

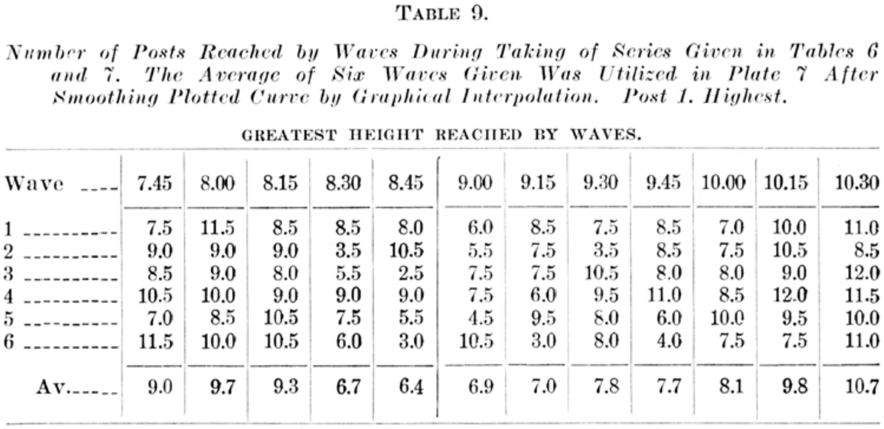

TABLE 9.

Number of Posts Reached by Waves During Taking of Series Given in Tables 6 and 7. The Average of Six Waves Given Was Utilized in Plate 7 After Smoothing Plotted Curve by Graphical Interpolation. Post 1. Highest.

GREATEST HEIGHT REACHED BY WAVES.

Wave	7.45	8.00	8.15	8.30	8.45	9.00	9.15	9.30	9.45	10.00	10.15	10.30
1	7.5	11.5	8.5	8.5	8.0	6.0	8.5	7.5	8.5	7.0	10.0	11.0
2	9.0	9.0	9.0	3.5	10.5	5.5	7.5	3.5	8.5	7.5	10.5	8.5
3	8.5	9.0	8.0	5.5	2.5	7.5	7.5	10.5	8.0	8.0	9.0	12.0
4	10.5	10.0	9.0	9.0	9.0	7.5	6.0	9.5	11.0	8.5	12.0	11.5
5	7.0	8.5	10.5	7.5	5.5	4.5	9.5	8.0	6.0	10.0	9.5	10.0
6	11.5	10.0	10.5	6.0	3.0	10.5	3.0	8.0	4.0	7.5	7.5	11.0
Av.	9.0	9.7	9.3	6.7	6.4	6.9	7.0	7.8	7.7	8.1	9.8	10.7

TABLE 9.

Number of Posts Reached by Waves During Taking of Series Given in Tables 6 and 7. The Average of Six Waves Given Was Utilized in Plate 7 After Smoothing Plotted Curve by Graphical Interpolation. Post 1. Highest.

11.